SAMPLING SOUTH POLE-AITKEN BASIN TO DETERMINE THE AGE OF THE IMPACT EVENT AND TEST THE CATACLYSM HYPOTHESIS. B. L. Jolliff[1], C. K. Shearer[2], N. E. Petro[3], and B. A. Cohen[3]. [1]Department of Earth & Planetary Sciences, Washington University in St. Louis, One Brookings Dr., St. Louis, MO 63130; [2]University of New Mexico, Albuquerque, NM; [3]Goddard Space Flight Center, Greenbelt, MD. (bjolliff@wustl.edu)

Summary: Regolith and rock samples collected at landing sites near the south pole, including near Shackleton crater, will contain materials ejected by the impact that formed the giant South Pole-Aitken (SPA) basin [1]. Shackleton crater occurs on an SPA basin massif and the impact that formed it excavated and mixed SPA material into the local regolith. Rock materials collected near Shackleton will be suitable for petrographic, geochemical, and chronologic analyses of SPA material. Based on the known diversity of rock fragments in Apollo regolith samples, regolith sieved on the Moon will yield rock fragments in the several mm to cm size range that are ideal for studies needed to identify and characterize SPA impact-melt materials. One kg of rock fragments would suffice, although greater quantities would insure that SPA impact melt and any pieces of mantle-derived rock that might be included would be sampled. Mobility to achieve sample diversity is not required but would mitigate concerns about non-representative sampling. A south-pole landing site for Artemis might also enable a robotic sample return from the interior of SPA. The return of samples from SPA basin to Earth for analysis is a Decadal Survey priority [2].

Scientific Rationale and Priority: The Moon holds an unparalleled and readily accessible record of early Solar System impact bombardment, and the South Pole-Aitken basin on the Moon's southern farside is a key scientific target because it is the largest and oldest well-preserved impact structure on the Moon. As such, its age and the ages of subsequent large impacts within SPA have the potential to provide a new understanding of early Solar System events relating to impact bombardment during the first ~500 million years following accretion of the planets. Analysis of samples from SPA, primarily chemical and mineralogical analyses and age determinations, will answer fundamental questions about the evolution of the early Solar System, including firm constraints on models for migration of giant planet orbits during the early epoch of Solar System history [3,4]. The samples will answer significant questions about the early evolution of the Moon and, by analogy, the terrestrial planets. The science objectives associated with samples from SPA are among the highest priority science for Solar System exploration as laid out by the Planetary Science Decadal Survey [2].

Samples from SPA will provide a test of the "cataclysm" or late-heavy bombardment that is implied by the analysis of lunar samples [5]. The SPA impact event was enormous, forming a basin some 2200×2500 km in size [6] and excavating materials from great depth, potentially including crust and mantle materials. Its effects on the Moon were global, forming a Moon-wide stratigraphic event. Determining the age of SPA will bracket the ages of other ancient, Pre-Nectarian basins on the Moon as well the origin of the apparent episode of igneous activity around 4.35 Ga [7-10]. Materials from SPA basin hold a record of the process of very large impact-basin formation [11] and will serve as ground truth for remote sensing of SPA basin materials. Volcanic rocks that occur in the SPA interior will contribute to our understanding of basin materials and chronology, and mantle heterogeneity. Paleomagnetic analyses will provide the oldest constraints on the lunar core dynamo, aiding our understanding of the Moon's earliest thermal evolution.

Chronology: Unravelling the impact chronology recorded by complex impact-melt rocks and breccias requires analysis of samples in the best terrestrial laboratory conditions and by modern, highly precise analytical methods. Coordinated petrographic and chronologic studies are required to understand the age data and to distinguish crystallization vs. impact ages. The impact that produced the SPA basin melted an enormous volume of rock and reset the age of a large part of the Moon. Rock materials collected from almost anywhere in the SPA basin or its ejecta will define the age of the SPA impact melt and potentially of a distribution of younger ages from the later, large impacts within SPA. Such age determinations will clarify whether the mechanisms proposed to account for the lunar cataclysm, inferred from Apollo samples, are compatible with the SPA samples. These samples will provide a record of the duration and timing of basin impacts on the Moon as well as a key absolute calibration point for the pre-4.0 Ga chronology [12,13].

The impact cataclysm hypothesis was first indicated by clustering of ages and identification of large-scale mobilization of Pb at ~3.9 Ga [5]. The 3.9 Ga age was also identified in Ar-Ar chronology [14]. The hypothesis was further supported by ~3.9 Ga Rb-Sr ages of melt rocks [15]. The Sm-Nd system is also an essential analytical method for lunar chronology because it is least disturbed by later impact events [16]. This system is important because SPA is old and has undergone later impacts that might have disturbed other chronometers. Because of this differential response of the chronometers to impact heating and metamorphism, samples from the SPA basin must be analyzed by all these techniques.

High precision methods (TIMS and MC-ICPMS) will be used on bulk and carefully separated materials, and in-situ analyses by SIMS will be conducted on mineral grains including zircon [e.g., 17], other Zr- and U-rich minerals, and phosphates [18].

Impact Basin Formation Processes: Numerical modeling of the SPA impact event has been the object of recent studies [e.g., 19]; these models will be further constrained using sample data. The age of SPA will constrain the thermal state of the Moon's lithosphere at the time of the impact. Samples will reveal the rock types and compositions of impact melt produced by the event and subsequent differentiation of the melt volume. Clasts in breccia and geochemical mixing analysis will reveal target lithologies, including deep crustal and mantle components. The compositions of SPA materials are relatively mafic (Fe-rich) [20]. However, until we have direct samples of the materials that give rise to the compositions, we will not know how to interpret them. The same holds for the mineralogical signatures seen in orbital spectroscopic data [21,22]. Mapping of mafic mineral signatures in crater central peaks and elsewhere [23] reflects a mixture of SPA substrate lithologies produced by differentiation of the SPA impact-melt body [24,25] and later volcanic rocks. Samples are essential to provide ground-truth for the orbital data.

Thermal Evolution of the Moon. Samples will be used to investigate sources and distribution of Th and other heat-producing elements to understand lunar differentiation and thermal evolution. Orbital measurements show a modest Th anomaly associated with the SPA interior, and it is possible that SPA is old enough to have occurred prior to the final migration and solidification of KREEP-rich materials. Coupling this signature with identification of host lithologies and age will enable new tests of models of lunar differentiation and the origin of the Moon's prominent asymmetries, and of whether the orbital SPA Th signature is associated with differentiation of the SPA impact melt body [26].

Sampling Approach: Because of the gardening process on the Moon, collecting the "right samples" just means collecting a large number of rocks or rock fragments. At any given site on the Moon, the regolith comprises many different rock types, mixed together by impact processes. Therefore, even though Shackleton crater excavated a massif that is likely to be largely composed of SPA material (including rocks), materials of other origins will also be collected. Compositional remote sensing [20] indicates that the regolith at the south pole is generally less mafic than in the interior regions of SPA, so it may be that other materials from the highlands outside of SPA have also been mixed into the regolith. Having a large number of samples permits discrimination of all the different rock types present and identification of SPA materials by their composition, mineralogy, and age. The best way to insure a large number of rocks is to collect them from the regolith, below the upper-most surface layer, which is highly gardened and exposed to cosmic rays and micrometeorite bombardment. Coarse sieving on the Moon to concentrate rock fragments will increase the scientific content of these samples manyfold. Large rocks are also important, but large rocks alone will not provide the diversity and statistics that are needed to identify all of the diverse components from SPA, possibly including mantle-derived rock fragments. The complexity of the integrated chronologic, geochemical, paleomagnetic, and petrographic analyses needed to achieve science objectives associated with determining the age of SPA, its full effects, and the diversity of materials representing it *requires* that samples be returned from the Moon.

Mobility to sample diverse locations is not a requirement; however, multiple samples from different locations will provide an added measure of certainty that diversity of lithologic components has been sampled. Drilling is also not required, but collecting sample material from depths below the upper 10-20 cm will enhance the yield of relatively fresh rock fragments and minimize the amount of sieving required. Astronaut training for this kind of sample analysis is minimal.

Ideally, characterizing a terrane as large as SPA with samples and unambiguously addressing Decadal Survey objectives will be done best by sampling at multiple sites separated by great distances. A robotic mission to sample the interior of SPA basin could be enabled by Artemis.

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